Attributing Standing Volumes and Harvest Volumes to CRBSUM Pixels with a Single-Tree Growth Model[1]

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[1]This chapter is an extension of "Calibrating a forest succession model with a single-tree growth model: and exercise in meta-modelling", presented at IUFRO World Congress, Tampere, Finland, August 1995. Additional authors of that paper included: Charles R. Hatch, Professor, University of Idaho, College of Forestry, Wildlife and Range Sciences, Moscow, Idaho 83843; Thomas M. Rice, Computer Specialist, USDA Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, 1221 S. Main St., Moscow, Idaho 83843; David L. Renner, Forestry Consultant, Charis Consulting, 242 N. Laurel, Genesee, Idaho, 83832; Jerome Korol, Quantitative Ecologist, University of Idaho, College of Forestry, Wildlife and Range Sciences, Moscow, Idaho 83843.

ABSTRACT

An existing single-tree, distance-independent model of stand development, the Forest Vegetation Simulator (FVS), was invoked to provide an empirical link between the Columbia River Basin SUccessional Model (CRBSUM), developed for a planning project for the Interior Columbia River Basin, and the real world. CRBSUM moves a pixel through a series of successional classes that represent the successional pathway. Each class is defined by a combination of potential vegetation, structural stage, and species type. Because the classification system used in CRBSUM is new, there is little empirical data available to attribute details of stand volumes and potential harvest volumes to the classes. The objective of this analysis was to provide objective estimates of the volumes for the CRBSUM simulations. These attributes were estimated by projecting collections of sample stand inventories with three geographic variants of FVS (Prognosis). The strong empirical bases upon which these variants of FVS are calibrated, combined with the actual sample inventories, provided estimates of timber volumes that would be affected by the disturbances scheduled into the CRBSUM scenarios.

INTRODUCTION

Forest succession can be modelled at two very different degrees of resolution, either as an area moving through a sequence of developmental stages, or as a collection of individual plants changing through birth, accretion, and death. In this paper, we report how models at these two extremes were linked to support a broad-scale planning project for the Columbia Basin in the Northwestern United States. The successional pathway model (Columbia River Basin SUccessional Model-CRBSUM) was developed by Keane and others (1995) for explicit use in the Interior Columbia River Basin Scientific Assessment (ICRB) project. The individual-tree model is the U.S. Department of Agriculture Forest Service's Forest Vegetation Simulator (FVS). (Note: The FVS modelling system is documented in the scientific literature as the Prognosis Model for Stand Development (Stage 1973, Wykoff and others 1982). However, along with its numerous geographical variants developed and maintained by the USDA Forest Service, Timber Management Service Center in Fort Collins, Colorado, the system is known collectively as FVS.).

Quantitative empirical data on stand development and on successional rates and pathways were already available in the Forest Vegetation Simulator (FVS) system. Many of the insect and pathogen effects are represented in the various pest extensions maintained by the Forest Service's Forest Pest Management Methods Application Group. This empirically based collection of information, although relevant, is not in a form that is useable by CRBSUM. The hiatus is due to inventory and computation limitations imposed by the vast, unprecedented geographic scope of the assessments.

The objectives for our endeavor relating to volume estimation were:

1. To provide a procedure for estimating standing biomass and effects of disturbances on the standing biomass for each pixel in the CRBSUM output.
2. To provide estimates of merchantable volumes that could be harvested under alternative management treatments.

VOLUME ESTIMATION

The FVS simulations estimate volume of the stand and volume of removals at each decade throughout the stand development. The question was raised whether these simulations could be analyzed to provide CRBSUM with estimated harvest volumes. There were, however, two major obstacles: (1) CRBSUM does not provide consistent successional ages for all pathways into a structural stage/Potential Vegetation Class cell, and (2) the inventory data used to initiate the simulations do not consistently provide stand ages. These obstacles were overcome by noting that CRBSUM does store the time remaining before transition to the next stage along the successional pathway for each pixel. This variable provided a crude "age complement." Thus, volumes per acre provided by the FVS simulations were tabulated by years remaining in the class for subsequent merging with CRBSUM output.

Specific steps were:

1. Prepare an FVS post-processor to classify a tree list into SAF cover type, and structural stage.
2. Obtain stand inventories in FVS format.
3. Run FVS from bare ground using the natural regeneration option and from existing inventory files of real stands to produce tree lists and volume summaries for each decade in a 300-year projection. Repeat for each method of harvest.
4. Process tree-list outputs through the classifier to assign a structural stage to each decade for each stand and method of harvest.
5. Sort the volume data by time remaining in the structural stage and by PVC, and geographic location (nearest National Forest).
6. Interpolate and extrapolate the mean volumes to cover the full range of classes represented in the CRBSUM simulations.

Classification into Structural Stages

Structural stages used in the Columbia River Basin Assessment as defined by Kevin O'Hara (1994) are displayed in table 1. Key elements in the classification are the number of distinct strata (age cohorts) in the stand and the sizes of trees in the uppermost stratum.

We viewed the tree lists generated by the FVS as we thought they would appear to a photo interpreter-in terms of crown cover and tree height. Crown area was estimated for each tree in the list using equations derived by Moeur (1981) for which there has been some testing against photo-based data (Moeur 1986). The tree list was then sorted by tree height.

Bounding the strata

Strata were defined by searching for discontinuities in the vertical crown structure of the sorted list. A tree was marked to indicate the potential top of a lower stratum if its top was lower than the top of the preceding tree by more than 30 percent of the total height of the preceding tree in the list. In our forests, dominant trees in closed stands have crowns that vary around 40 percent of total height. Therefore, the 30 percent criterion would translate into an overlapping by the shorter tree of the lower quarter of the taller tree's crown.

In this process of defining gaps in the crown structure, it was important to ignore tree records that represent an insignificant number of trees in the stand because of previous mortality or because of harvest in the class that the record represents. The absolute magnitude of this threshold will vary with the sampling intensity of the stand inventory, so two criteria were used to ignore inconsequential records. A tree record was ignored if the record represented less than 0.001 trees per acre (0.00247 trees per hectare) or if the smaller tree represented less than 0.01 times the contribution to density of the previous tree. (Note: Most sampling rules produce lists in which the number of trees represented by a record increases as tree size decreases.)

Next, the list of potential gaps was sorted, and the two largest gaps were deemed to bound three potential strata. Total crown cover represented by the tree records in a potential stratum must equal or exceed 5 percent of ground surface area to be considered a valid stratum. This cutoff was selected to agree with the instructions given to the photo interpreters. Size of trees in the dominant stratum was calculated by finding the tree record at the 30th percentile in the distribution of crown cover. The mean diameter at breast height (dbh) of the nine tree records centered on the 30th percentile record in this sorted list defined the size assigned to the stratum. The 30th percentile was chosen instead of the 50th percentile because the larger trees are more readily visible on the photos.

Development of an example stand in the cedar/hemlock Potential Vegetation Type, generated *ab initio* by the Regeneration Establishment Model (Ferguson and Crookston 1991), is illustrated at 30 year intervals in figures 1 through 5 (drawn by the Stand Visualization System [McGaughey and McCarter 1995] from tree lists generated by FVS). The classification algorithm applied to the list of trees at 10 year intervals in the simulation showed that the stand passed through five structural stages: nonforest, stand initiation (duration = 10 years), stem exclusion (50 years), understory reinitiation (20 years), back to stem exclusion (30 years), and finally to Old forest single stratum (30 years).

HARVEST SIMULATION

Harvest disturbances were grouped into four types: (1) complete stand harvest or partial harvest, which in turn is divided into (2) a thin from below, (3) a shelterwood cut, and (4) a selective harvest spread across all size classes of trees. During each simulation run of CRBSUM, a random number generated from a uniform distribution was compared to the disturbance probability for each of the types of harvest of a given pixel. If the pixel is selected for harvest, it is reclassified according the identified disturbance pathway (Keane and others 1996).

CRBSUM was modified to record, for each pixel designated for harvest, the years remaining before the pixel would move to the next successional stage, or the transition year, as well as a unique harvest code. This harvest code key to an associated table with information about the PVT, structural stage, and type of harvest. CRBSUM also records this same information on a Volume Map, capturing the harvest data in a spatial environment. This data were then overlaid with other map themes, including management region, National Forest, and watershed, and compiled in a database. A report was generated from this database providing all the data necessary to compute volumes. In a subsequent calculation, a volume per acre cut summarized from the FVS simulations was multiplied by the acres cut in the CRBSUM simulation. This procedure is a simple refinement of the acres disturbed by harvest that was already a planned report from CRBSUM.

The merit of this approach is that it relies on the future course of development of stands as simulated by FVS without relying on the effect of past stand development as embodied in successional age. The volume estimate is derived by a method that is logically independent of the analysis of residence time. It does not, therefore, require any assumptions that might contradict the logic behind the derivation of the parameters that are input to CRBSUM, and which ultimately define the model. It does, however, rely on the ability of the classification logic to properly label the structural stages. The responsibility for inserting a stand at the appropriate successional age within a class during the CRBSUM run remains with those experts who define CRBSUM by providing the residence times.

For complete stand harvest, the volume that could be harvested by clear-felling at any time is simply the estimated standing volume produced for a non-management scenario. For partial harvests, multiple runs of the same stand invoked partial harvests scheduled at different times in the stand's development. FVS can, through use of the event monitor (Crookston 1990), schedule a simulation of a harvest when certain stand conditions are met. This capability permits the imposition of constraints on whether sufficient volume would be removed for an economically viable operation. For thinnings, the constraint on whether to thin or not can be made conditional on the density and species composition of the stand. These prescriptions can be made specific for the management scenario under which the product yield is to be calculated.

SOURCE DATA

Two sources of data were analyzed. One set for the grand fir, cedar, and hemlock classes of potential vegetation starts each simulation from "bare ground" by using the Regeneration Establishment component of the Inland Empire variant of FVS (Prognosis Model for Stand Development) to provide estimates of in-growth (Ferguson and Crookston 1991). The model is run for the 158 stands, representing the combinations of slope, aspect, elevation, and habitat type that were used in assembling the tables of stand development by site index and age (Stage and others 1988). The weights for these stands are proportional to the incidence of these classes in the forests of the Inland Empire as derived from inventories of the National Forests and the Forest Service's Forest Inventory and Analysis for the remaining forested area.

The second set of analyses uses ground-based inventories supplied by the Forest Service's Timber Management Service Center in Fort Collins, Colorado. These stands were selected in proportion to the area of forested lands in the Interior Columbia River Basin. A simulation of the development of each of these stands will be analyzed by the same procedures outlined above. The analyses differ because the initial successional ages of the Inventory stands cannot be determined. Hence, the simulation can only define a minimum time to the first transition. Thereafter, the information is the same as that derived from the bare-ground analyses.

The Regeneration Model is invoked in the FVS system after silvicultural treatments (thinning or harvest) or by the Event Monitor whenever specified conditions are attained in the course of stand development. For the analyses of normal successional pathways, the latter alternative was used. The Regeneration Model was called whenever natural mortality caused the Crown Competition Factor (CCF) to fall below 85 and the mean dbh of the stand was greater than 15 cm.

Problems of Scale

The broad-scale ICRB analyses have a resolution of 1 km^2 per pixel. The inventory data, on the other hand, are from clusters of 5 to 15 sample points per stand or location. At each sampling point, a combination of a small fixed-area plot and a variable-radius plot design with basal-area factors of about 1.5 m^2 / ha. were installed to produce a list of trees with their associated sampling probability and tree attributes. This discrepancy in the spatial extent of the analysis units must be considered when comparing the successional pathways in CRBSUM with those generated by FVS. Classes generated from FVS data will have larger sampling variability because they represent small areas. Therefore, the rare or unusual classes will occur more frequently in the FVS simulations than in CRBSUM.

RESULTS

Harvest Volume

Harvest volumes for each of the four harvest types (clearcut, thinning, shelterwood, and partial cut) were averaged separately for each combination of time remaining to Successional Stage transition, PVT, structural stage, and the National Forest from which the inventory data had been obtained. This last level of delineation provided a crude means to localize the volume data for effects not related to PVT and structural stage. In addition to measures of cubic volume, basal area and numbers of stems were also summarized so that the relative size of the trees harvested could be displayed.

The final step was to prepare summary software to extend the volume data for each geographic area. Although the inventory data were extensive, there were inevitable gaps when the areas harvested in the CRBSUM simulations were matched with the FVS-produced volume data. Therefore, the summary software was programmed with substitution rules. Default data were sought first from nearby geographic areas, then from similar types of potential vegetation with adjustments for relative productivity.

As a final check on the calculation of volumes, the Forest Service has contracted with ESSA Technologies, Ltd., to incorporate the volume calculations into the Vegetation Dynamics Development Tool simulation package (VDDT). With this tool, we can identify and evaluate possible inconsistencies in volume development that are the consequence of linking these two disparate modelling systems.

DISCUSSION

There were two significant outcomes of this endeavor. First, we showed that it was possible to provide an empirical foundation for a purely subjective model by building links to a model with a strong empirical basis. However, the linkage does not replace all subjective assumptions. Rather, it replaces the need for assumptions that can be verified only through long-term studies with assumptions that can be verified by one-time observations.

Second, we showed that it is possible to provide a subjective successional pathways model with objective estimates of stand attributes, such as standing biomass and harvest volumes, without the need for field sampling.

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TABLE CAPTIONS

Table 1--Definition of structural stages.

FIGURE CAPTIONS

Figure 1--Example of Stand Initiation Structural Stage based on classification of the Forest Vegetation Simulator tree list at 10 years.

Figure 2--Example of Stem Exclusion Structural Stage based on classification of the Forest Vegetation Simulator tree list at 40 years.

Figure 3--Example of Understory Reinitiation Stage based on classification of the Forest Vegetation Simulator tree list at 70 years.

Figure 4--Example of Stem Exclusion Structural Stage based on classification of the Forest Vegetation Simulator tree list at 100 years.

Figure 5--Example of Old Forest-Single Stratum Structural Stage based on classification of the Forest Vegetation Simulator tree list at 130 years.

Figure 6--Comparison of rates of succession as modelled by CRBSUM and Forest Vegetation Simulator for Cover Types of the Cedar/Hemlock Potential Vegetation Type.

APPENDIX I

Retrogression Algorithm

Steps to avoid illogical transitions:

1. Place a marker in each cell of the "From/To" transition matrix that signifies retrogression (information obtained from the successional pathway diagrams).

2. For each developmental sequence, classify the tree list into the corresponding sequence of classes.

3. Scan the class sequence for transitions.

4. If the transition is not retrogressive, then enter data for residence time. Otherwise (the transition is retrogressive) compare the mean diameter of trees in the dominant stratum of the source class to the upper boundary of the receiving class. If the difference is less than 1/6 of the interval spanned by the definition of the receiving class, then change the receiving class to equal the source class (erase the retrogression).

Note: Decreases in mean diameter that cause retrogression may be a consequence of new regeneration entering the tree list. The above algorithm, in effect, decreases the boundary diameter of the more advanced class, so that the stand does not so quickly leave the advanced class.

Table 1--Definition of structural stages.

Number of strata	Diameter size class of uppermost stratum		
	Seedlings/ saplings < 5 inches	Pole/small /medium sawtimber 5 - 25 inches	Large sawtimber >25 inches
1	Stand initiation	Stem exclusion	Old forest single stratum
2	Not applicable	Understory reinitiation	Old forest multi-strata
3+	Not applicable	Young forest multi-strata	Old forest multi-strata

Figures 1,2,3,4 and 5 not available